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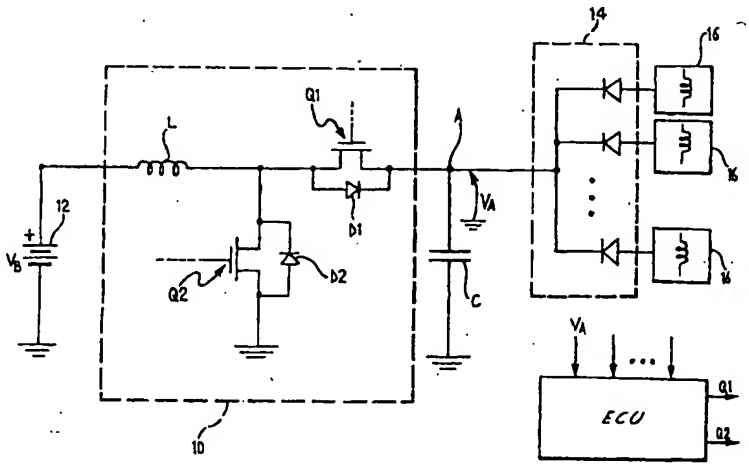
(54) A voltage-regulator circuit for the electromagnetic driving of the valves of an internal combustion engine

(57) A voltage-regulator circuit for the electromagnetic driving of the valves of an internal combustion engine is described and comprises: an energy-storage capacitor (C) for coupling to a current-recirculation network (14) associated with at least one respective actuating coil (16) for each valve, and a switching current-regulator circuit (10) disposed between a direct-current power supply (12) and the capacitor (C). The voltage-regulator circuit is arranged to operate as a booster of the voltage from the power supply (12) towards the recirculation network (14) and as a reducer of the voltage from the recirculation network (14) towards the power supply (12).



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Description

[0001] The present invention relates to a voltage-regulator circuit for the electromagnetic driving of the valves of an internal combustion engine, of the type defined in the preamble to Claim 1 and, more particularly, to a circuit of this type for recovering the energy stored in the valve-actuating coils.

[0002] A system for the electromagnetic driving of the intake and exhaust valves of an internal combustion engine comprises, for each valve, at least one respective actuating coil which can be connected selectively to a supply circuit. This circuit supplies an actuating current to each coil in order to open and/or to close the valve.

[0003] The essential requirement in the driving of the intake and exhaust valves of an engine is precision in the definition of the actuation times.

[0004] This precision can be achieved by rapid actuation of the valve, for which it is necessary for the voltages available in the supply circuit to be sufficiently higher than the battery voltage available at present in most vehicles (12 volts), for example, of the order of 42 volts.

[0005] It is also necessary to use a circuit which ensures rapid recirculation and possibly recovery of the discharge current typical of an inductive load such as the valve-actuating coil, thus limiting dissipation towards an earth conductor.

[0006] Since the load represented by the actuating coil is a highly inductive load, it is preferable for the current recirculation also to take place with the supply, to the terminals of the coil, of voltages which are sufficiently higher than the normal battery voltage.

[0007] In the prior art, a circuit for driving an inductive load in general, and valve-actuating coils in particular, is formed with the provision of a Zener power diode which connects the load to an earth conductor in order to discharge the energy stored in the load.

[0008] The greatest disadvantage of this solution is that it does not permit recovery of the energy used to drive the coils. Moreover, since two actuating coils are preferably required for each valve, and since the total number of valves of an engine is large (for example, 4 valves per cylinder for 4 or more cylinders), the power dissipated reaches values of hundreds of watts, presenting further problems of heat dissipation and efficiency of the system.

[0009] In order to allow the discharge current in the actuating coils to decay rapidly and the energy stored therein to be recovered, limiting dissipation, the subject of the invention is a voltage-regulator circuit for the electromagnetic driving of the valves of an internal combustion engine having the characteristics recited in the appended claims.

[0010] The solution according to the invention consists in providing the voltage-regulator circuit with a capacitive energy-storage element for receiving a discharge current from the coils and for conveying this current in a controlled manner to a supply (or battery) by means of a switching current-regulator circuit.

[0011] The solution according to the invention also enables the capacitive element to be charged rapidly by means of the same current-regulator circuit in order to provide the terminals of the coils with a voltage sufficiently higher than the battery voltage without waiting for the capacitive element to be charged purely by the discharge currents of the coils.

[0012] With the use of the solution proposed, it is possible to limit the power dissipated to earth by the circuit, ensuring greater efficiency of the circuit and advantageously reducing the impact of the valve-driving system on the energy balance of the vehicle.

[0013] Further characteristics and advantages of the invention will be described in greater detail in the following specific description of an embodiment thereof, given by way of non-limiting example, with reference to the appended drawing which shows a circuit diagram of the voltage-regulator circuit according to the invention.

[0014] The voltage-regulator circuit comprises a storage capacitor C arranged between a node A and an earth conductor, and a switching current-regulator circuit 10 coupled to the capacitor C, and more precisely to the terminal of the capacitor corresponding to the node A.

[0015] The current-regulator circuit 10 is coupled, on the opposite side to the node A, to a battery 12 or to another direct-current supply which can provide a supply voltage V_B. At the node A there is a voltage V_A relative to the earth conductor which, in operating conditions, is substantially equivalent to a predetermined reference voltage V_{ref}, considerably greater than the supply voltage V_B.

[0016] A recirculation network, generally indicated 14, and associated with a plurality of actuating coils 16 of the valves to be driven, is also connected to the node A.

[0017] In order to open and close the corresponding valves, these coils 16 can be connected selectively, by known circuits which are not shown in the drawing and are not referred to in the description, to a supply circuit which, for example, is connected to the same battery 12. The recirculation network 14 is arranged to recirculate the transient discharge current which is generated every time each coil 16 is disconnected from the supply circuit.

[0018] In greater detail, the current-regulator circuit 10 comprises an inductor L, of which a first terminal is connected to the battery 12 and a second terminal is connected to the node A via a first MOSFET transistor Q1 and to the earth conductor via a second MOSFET transistor Q2. For completeness, the parasitic diodes D1 and D2 present between the drain and source electrodes of the transistors Q1 and Q2, respectively, are indicated in the drawing.

[0019] A control unit shown separately is indicated

ECU. The control unit is arranged to receive an input signal indicative of the voltage V_A present at the node A and to control the transistors Q1 and Q2 at their gate electrodes.

[0020] In operating conditions, during an initial, transient stage, the voltage-regulator circuit is driven by the control unit (ECU) as a voltage booster for rapidly increasing the voltage V_A until a voltage corresponding to the predetermined reference voltage V_{ref}, and such as to permit recirculation of current at high voltage, is reached.

[0021] The control unit detects the voltage V_A present at the node A and drives the transistors Q1 and Q2 accordingly. When the voltage V_A is below the predetermined value V_{ref}, the control unit cuts off the transistor Q1 and turns the transistor Q2 on, drawing current from the battery, through the inductor L, towards the earth, charging the inductor. The control unit also monitors the current flowing in the transistor Q2 and, when this reaches a predetermined intensity, cuts off Q2 and turns Q1 on, causing the inductor L to be discharged to the storage capacitor C, which is consequently charged. The control unit then repeats the cycle until the voltage at the node A reaches the predetermined value V_{ref}.

[0022] In steady state operation, the storage capacitor C is charged, by means of the recirculation network 14, by the transient discharge currents of the coils 16.

[0023] If the storage capacitor C is over-charged by the recirculation current coming from the coils of the valves, the voltage V_A exceeds the predetermined reference value V_{ref}; the control unit (ECU) recognizes this condition and drives the voltage-regulator circuit as a voltage-reducer in order to bring the voltage V_A back to a value as close as possible to V_{ref}, enabling the storage capacitor C to release current towards the battery and to recharge the battery.

[0024] As long as the voltage detected at the node A is greater than the predetermined value V_{ref}, the control unit drives the transistor Q2 in the off state and the transistor Q1 in the on state, returning current from the storage capacitor C, through the inductor L, to the battery 12, charging the inductor. The control unit also monitors the current flowing in the transistor Q1 and, when this reaches a predetermined intensity, cuts off Q1 and turns Q2 on, causing the inductor L to be discharged towards the battery 12 which is consequently recharged.

[0025] In this preferred embodiment, a current sensor is not required since the predetermined current intensity which leads to the switching of the transistors Q1 and Q2, and the conduction times of the transistors, can be calculated analytically by the control unit exclusively on the basis of the information relating to the voltage value at the node A, to the voltage value V_B, and to the inductance of the inductor L.

[0026] This solution is advantageous since it ensures greater efficiency in the discharge of the coils and consequently in the recharging of the battery and enables the dimensions of the circuit used to be reduced.

Claims

1. A voltage-regulator circuit for the electromagnetic driving of the valves of an internal combustion engine, each valve comprising at least one respective actuating coil (16) which can be coupled selectively to a power supply circuit,

   the voltage-regulator circuit being characterized in that it comprises:

   - at least one capacitive energy-storage element (C) for coupling to a current-recirculation network (14) associated with the at least one respective coil (16) of each valve, and having a first terminal connected to the recirculation network (14) and a second terminal coupled to an earth conductor, and

   - a switching current-regulator circuit (10) which can be disposed between a direct-current power supply (12) and the at least one capacitive element (C),

   the at least one capacitive element (C) being adapted to have, at the first terminal, in a steady state operating condition, a voltage (V_A) substantially corresponding to a predetermined reference voltage (V_{ref}) greater than the voltage (V_B) supplied by the power supply (12),

   the voltage-regulator circuit being arranged to operate as a booster of the voltage from the power supply (12) towards the recirculation network (14) and as a reducer of the voltage from the recirculation network (14) towards the power supply (12).

2. A circuit according to Claim 1, characterized in that the current-regulator circuit (10) comprises:

   - an inductive element (L) having a first terminal for coupling to the power supply (12) and a second terminal for coupling to a first terminal of the at least one capacitive element (C) via first switching means (Q1), and

   - second switching means (Q2) connected between the second terminal of the inductive element (L) and the earth conductor.

3. A circuit according to Claim 1, characterized in that the at least one capacitive element (C) is adapted

to:

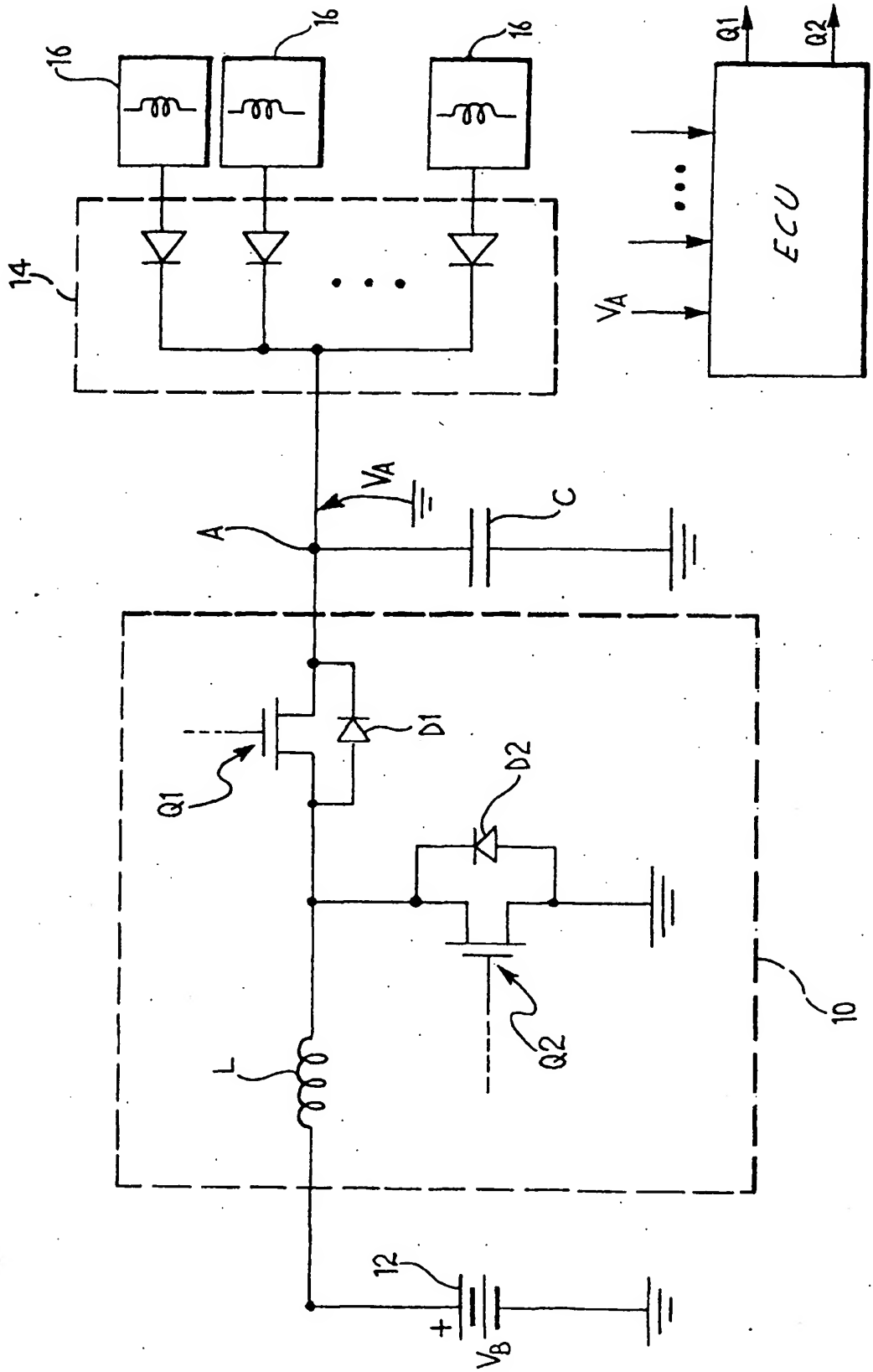
- receive a current from the power supply (12) via the current regulator (10) when the value of the voltage at the first terminal (V_A) is below the predetermined reference-voltage value (V_{ref}),

- receive from the recirculation network (14) a transient discharge current which is generated every time each coil (16) is disconnected from the power supply (12), and

- release a current towards the power supply (12) via the current-regulator (10) when the value of the voltage at the first terminal (V_A) is greater than the value of the predetermined reference voltage (V_{ref}).

4. A voltage-regulator circuit according to any one of the preceding claims, characterized in that it comprises a control unit (ECU) for detecting a voltage value (V_A) at the first terminal of the at least one capacitive element (C) and for controlling conduction in the first and second switching means (Q1, Q2) in predetermined manner so as selectively to cause current to be supplied from the power supply (12) towards the at least one capacitive element (C) or vice versa, in dependence on the voltage value (V_A) detected.

5. A circuit according to any one of Claims 2 to 4, characterized in that the first and second switching means (Q1, Q2) are formed as MOSFET transistors.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EUROPEAN SEARCH REPORT

Application Number
EP 99 12 4310

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 10, 31 August 1998 (1998-08-31) & JP 10 131726 A (ISUZU MOTORS LTD), 19 May 1998 (1998-05-19) * abstract *	1	F01L9/04
A	EP 0 376 715 A (ISUZU MOTORS LTD) 4 July 1990 (1990-07-04) * column 2, line 17-30 * * column 3, line 7 - column 5, line 29 * * figures *	1	
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A	US 5 793 599 A (SCHMITZ GUENTER) 11 August 1998 (1998-08-11) * the whole document *	1	
A	US 4 801 859 A (DISHNER BRYAN W) 31 January 1989 (1989-01-31) * column 2, line 50-58; claims * * figures *	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F01L

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 April 2000	Klinger, T

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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